THE EFFECT OF PRESCRIBED FIRE ON NUTRIENT CYCLING CHARACTERISTICS OF THE PONDEROSA PINE FOREST FLOOR

EC-222
16-693-GR

FINAL REPORT

The effect of prescribed fire on nutrient cycling characteristics of the ponderosa pine forest floor

by

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to

Eisenhower Consortium for Western Environmental Forestry Research

April 26, 1978

Introduction

Before settlement by European man, wildfires in southwestern ponderosa pine (Pinus ponderosa Laws.) occurred at fairly frequent intervals, perhaps every five to twelve years (Biswell 1972, Cooper 1961, Weaver 1951, and others). That ponderosa pine has evolved in the presence of periodic fire is widely recognized, and, in fact, it is considered as a classic example of a fire adapted forest ecosystem (Weaver 1974, Biswell 1972).

The effects of fire exclusion in fire-adapted forest types such as ponderosa pine has been blamed for such negative environmental impacts as: 1) overstocked sapling patches, 2) reduced growth in all size classes, 3) stagnated nutrient cycles, 4) increased disease, infestation, and parasites (e.g. Fomes, bark beetle, dwarf mistletoe), 5) decreased seedling establishment, 6) decreased forage quality and quantity, 7) increased fuel loading, 8) increased occurrence of fuel ladder due to unthinned sapling patches, and 9) increased severity and destructive potential of wildfires. Due to its apparent low cost and high benefits, forest managers are turning to prescribed burning in an attempt to alleviate these problems (Biswell 1972).

This paper reports the effects on forest floor chemical properties of prescribed understory burning in ponderosa pine in Northern Arizona. This research was conducted in cooperation with John H. Dieterich and Stephen S. Sackett, Fuel Management Project, Rocky Mountain Forest and Range Experiment Station, U.S.F.S., Tempe, Arizona.

Literature Review

Most of the published literature on the effects of fire on soils, forest floor, and nutrient cycling involves studies of the impact of wildfires. Generally, prescribed burning occurs under conditions of low wind speed, low air temperature, and high relative humidity resulting in a less intense fire than would occur under wildfire conditions. Thus it is difficult to draw inferences about the environmental impact of prescribed burning from studies of wildfire.

The most obvious and immediate effect of prescribed burning on nutrient cycling is the mineralization of the forest floor, downed woody fuels, and understory vegetation. The amount of organic matter removed varies considerably with fuel loading and moisture content as well as burning conditions. At extremely hot microsites, virtually all of the forest litter may be consumed. However, prescribed fires in most forest types usually remove comparatively small amounts of organic matter (Burns 1956, Wells 1971, Fuller et al. 1955, Ffolliott et al. 1977). Since fuel conditions and fire behavior are so variable, litter removal is "patchy" with unburned islands of litter frequently found even in severe burns (Sweeney and Biswell 1961).

Fire removes variable amounts of carbon, oxygen, and nitrogen from the forest floor. Cations (e.g. calcium, magnesium, potassium) are left behind, although at extremely hot microsites, as where heavy woody fuel has burned, some potassium may be volatilized.

Burning has been shown to increase the pH and cation content of both the forest floor and the mineral soil for most forest types

(Viro 1969, Wells 1971, Ahlgren and Ahlgren 1960), Fuller et al. (1955).

The effects of fire on nutrient concentrations in the mineral soil also vary considerably with vegetation and soil type as well as fire characteristics (e.g. Wells 1971, Jorgensen and Wells 1971, Grier 1975, St. John and Rundel 1976, Viro 1969). In ponderosa pine in California, Klemmedson et al. (1972) found no significant change in nitrogen concentration in the mineral soil. Fuller et al. (1955) found increases in available nutrients in the mineral soil to vary with burn intensity in ponderosa pine in Arizona. Vlamis et al.(1955)using a bioassay technique concluded that prescribed burning in California ponderosa pine increased availability of both nitrogen and phosphorus in the mineral soil. Using the same bioassay technique, Wagle and Kitchen (1972) found increases in available nitrogen in Arizona ponderosa pine which had been recently burned by a wildfire.

This increased nutrient availability usually results in enhanced vegetation growth (Ahlgren and Ahlgren 1960). Vlamis et al. (1955) showed an increase in productivity of bioassay plants grown on prescribed-burned ponderosa pine soils in California as did Wagle and Kitchen (1972) for wildfire burned ponderosa pine soils in Arizona.

Objectives

The objective of this research was to determine the short term effects on the forest floor of prescribed understory burning in ponderosa pine. Specific parameters measured include:

1. Organic matter content
2. Total macronutrient content (Ca, Mg, K, N, and P)
3. Cation exchange capacity
4. Exchangeable cations (Ca, Mg, K)

Methods

This research was conducted in coordination with the Burning Interval Study of the Fuel Management Project, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona. The overall study design for this project is detailed by Sackett and Dieterich (unpublished). Basically, there are twenty-one 1 ha (2.5 acre) plots (Appendix A) established at the Fort Valley Experimental Forest, approximately 11 km northwest of Flagstaff, Arizona, at an elevation of 2195-2255 m.

Site Description

The climate can be described as subhumid to humid combined with cool temperatures; the ponderosa pine type in Arizona is also characterized by deficient early summer moisture. Mean annual temperature at Flagstaff is 7.5^{o}C, and the mean annual precipitation at Fort Valley is 56.7 cm (Schubert 1974) with approximately one-half of the precipitation falling in the form of snow. The average frost free growing season is 135 days (Schubert 1974).

The study area is located on the boundary of the area covered by the San Francisco Peaks soil report (Meurrise, unpublished). By extension of his soil type boundaries to the study area I have inferred that the soil is a Brolliar stony clay loam, tentatively classified by Meurrise as a fine, montmorillontic, frigid, typic, Argiboroll.

Ponderosa pine is virtually the only tree species at the study site. The predominant size class is trees which are approximately 20 to 50 cm dbh (diameter at breast height), with scattered groups

of 5-20 old age trees ranging from 60-120 cm dbh, and dense "doghair" thickets of sapling sized trees ranging from 2.5 to 7.6 cm dbh.

Logging activity, except for localized firewood cutting of dead trees near roads, has not taken place since the mid-1940's (historical records, Coconino National Forest, Flagstaff, Arizona). The last fire occurred in the area approximately ninety years ago and before that time fires occurred periodically at an average interval of 3-5 years based on tree ring analysis of fire scars (J.H. Dieterich, personal communication).

The prescribed burning of the study area was conducted on 5 November, 1976, starting at 17:30 hours and concluding around 22:30 hours, although some heavy fuels were still burning several weeks later. Pre-fire air temperature was approximately 5-10^{o}C, with a downslope wind of 5-12 kph (J.H. Dieterich, personal communication). The forest floor was quite dry since there had been no appreciable precipitation at the study site for well over a month prior to the burning.

Forest Floor Sampling

Twenty 0.93 m^2 (1 ft.^{2}) samples of forest floor were collected systematically from each of the 1 ha. (2.5 acre) one year burn plots before burning, immediately after burning, and 8 months after burning (Appendix B). Sample points with less than 50% of their surface area covered by needles (e.g. points with greater than 50% surface area in rocks, logs, or tree stems) were excluded. Samples were sieved (2 mm stainless steel sieve) and the less than 2 mm fraction was analyzed for organic matter content by loss on ignition. Total cation (calcium, magnesium, potassium) content was determined

on a 6N HCL extract of the ash from the organic matter determination. Cation determination was by atomic absorption spectrophotometry (Perkin Elmer 1974). Samples were composited by fours for each basal area point for nitrogen, phosphorus, exchangeable cation, and cation exchange capacity determinations. Total phosphorus and total nitrogen was determined by colorimetric procedures on a modified Kjeldahl digest using the Technicon Auto Analyzer (Technicon, 1974). Cation exchange capacity and exchangeable cations were determined using the ammonium acetate procedure of Wilde et al. (1972).

Statistical analysis was based on a paired _t_ statistic test. Treatment effects were considered to be significant only if the probability of their being true treatment effects exceeded 95% ($p = .05$). One-tailed tests were used in cases where the _a priori_ assumption was that the treatment would decrease (e.g. organic matter content) or increase (e.g. nutrient concentration) the variable being considered.

Results

The following results are based on chemical analysis of the fine fraction of the forest floor, i.e. that which would pass a 2 mm sieve. Thus, caution should be used in attempting to expand these results to the entire, unsieved forest floor.

The organic matter content of the fine fraction of the forest floor decreased by a total of 398 g/m^2 or 20% as an immediate result of the prescribed burning (Table 1). Eight months after burning, the forest floor decreased by an additional 401 g/m^2 (Table 1).

Total macronutrient concentrations varied in their response to burning (Table 1). Calcium concentrations of the forest floor increased almost 3 fold immediately after burning. While the increase from November 1976, to June 1977 was not significant, it does show that calcium concentrations did not decrease during that period.

Magnesium showed a similar, though somewhat lower, increase than calcium immediately after burning (Table 1). Contrary to the results for calcium, magnesium concentrations declined significantly by June, 1977.

Like calcium and magnesium, potassium concentrations increased significantly immediately after burning. Of the three cations, only potassium showed a significant increase in concentration between November 1976, and June 1977.

Nitrogen concentration increased significantly immediately after burning (Table 1). The nitrogen concentration 8 months after burning had declined to pre-burn levels and was not significantly different from either pre-burn or post burn levels.

Burning significantly increased the phosphorus concentration of the forest floor by approximately one half (Table 1). By 8 months after burning (June 1977) phosphorus concentration results suggest a slight increase, although it was not significantly higher than the November, 1976, samples taken immediately after burning. However, the June, 1977, samples were significantly higher than pre-burn samples.

Budgetary changes in the fine fraction of the forest floor were calculated by multiplying the organic matter content by the nutrient concentrations in Table 1. The results are presented in Table 3.

Nitrogen decreased by 3.4 g/m^2 immediately after burning. All other macronutrients measured were increased by the burning. Calcium showed the greatest increase (35.8 g/m^2), followed in order by magnesium (10.8 g/m^2), potassium (2.27 g/m^2), and phosphorus (0.72 g/m^2).

All macronutrient contents decreased between November, 1976, and June, 1977. In order by magnitude the decreases were: nitrogen (12.3 g/m^2), magnesium (7.7 g/m^2), calcium (6.1 g/m^2), phosphorus (0.87 g/m^2), and potassium (0.15 g/m^2).

Discussion

In the absence of fire, forest floor components vary in their contribution to the forest's available nutrient supply according to their decomposability (Covington 1976, Cromack and Monk 1975). The larger components, such as branches, whole needles, logs, cones, etc., have relatively long turnover times by microbial processes. For this reason, forest biologists generally analyze only the fine, sieved fraction in nutrient cycling studies. Sweeny and Biswell (1961) found a 22 percent decrease in the forest floor duff following a broadcast slash burn in ponderosa pine in California. Also in California ponderosa pine, Klemmedson et al. (1962) found only minor decreases in duff following piled slash burning. Both of these studies involved burning with the forest floor fairly damp.

When compared to some other ponderosa pine prescribed and slash burning under hotter burning conditions, the losses from my study seem fairly modest. Davis et al. (1966), working in Arizona ponderosa pine, found a 75 percent reduction in forest floor depth following a prescribed burn. An 80 to 85 percent

reduction in the total of slash plus litter was observed by Klemmedson (1976) in piled slash burning of Arizona ponderosa pine.

One of my more interesting results is that the organic matter content of the forest decreased by an additional 401 g/m^2 in the 8 months following burning, November, 1976, through June, 1977. Presumably, most of this loss is due to accelerated decomposition brought about by more favorable pH, nutrient, moisture, and temperature conditions (Fuller et al. 1955). That this oxidation of the forest floor occurred through microbial processes may be especially important, since nutrients mineralized in this manner are released more gradually than the sudden pulse brought about by fire. Furthermore, nitrogen release in burning probably often results in considerable volatilization representing a net loss to the ecosystem, whereas nitrogen released by accelerated decomposition following burning would be in a form (ammonium and nitrate) readily absorbed by plants and microbes.

The total macronutrient concentration of the forest floor was increased for all elements measured. This concentrating effect of fire has been widely observed and is attributed to the oxidation of organic matter, with most of the nutrients left behind in the ash. Fuller et al. (1955) found increases in concentrations of nitrogen, phosphorus, sodium, potassium, and calcium in the forest floor following burning in Arizona ponderosa pine.

Burning increased the nutrient content (g/m^2) of the fine fraction of forest floor for all macronutrients except nitrogen. This increase in the total nutrient content is undoubtedly due to the addition of calcium, magnesium, potassium, and sodium in

the form of ash from the large forest floor components (e.g., logs, branches, twigs, whole needles, cones) and understory vegetation burned. Before burning, these components would not pass through the sieve, whereas, after burning they would, in the form of ash.

The decrease in nitrogen of 3.4 g/m^2 (Table 3) is attributed to volatilization. This loss of less than 10 percent of the forest floor fine fraction's total before burning is minimal. The loss was not directly proportional to organic matter consumed by the fire as evidenced by the increase in nitrogen concentration immediately after burning (Table 1). This was a fairly cool fire and various researchers (Evans and Allen 1971 and Knight 1966) have shown that nitrogen volatilization is a direct function of temperature.

During the 8 months after burning all macronutrient contents of the forest floor decreased. The greatest decreases were for nitrogen, magnesium, and calcium. These decreases are the result of transfer to the mineral soil by leaching or surface runoff. Root uptake directly from the forest floor is probably minimal in this forest type. The fate of nutrients leached into the mineral soil would depend on whether they were immobilized in microbial biomass, adsorbed onto exchange sites, chemically precipitated, taken up by plants, or leached out of the ecosystem in stream flow.

Increases in nutrient concentrations in the mineral soil following burning of ponderosa pine are suggested by the work of Fuller et al. (1955), Wagle and Kitchen (1972), Vlamis et al. (1955),

and Campbell et al. (1977). Increases in productivity of understory vegetation following burning in ponderosa pine have been found by Harris (1978), Ffolliot et al. (1977), Pearson et al. (1972), and others. Furthermore, Harris (1978) has found that some nutrients increase in concentration in the understory vegetation. Also, ponderosa pine trees have shown an increase in growth after burning (Morris and Mowat 1958). The immobilization of phosphorus by calcium carbonate, iron, and aluminum in the mineral soil is common (Vlamis et al. 1955, Buckman and Brady 1969). Finally, the bicarbonate solution transfer system can result in the retention of cations in mineral soil (Cole et al. 1975, Campbell et al. 1977).

From the above, it is apparent that numerous mechanisms exist which could result in rentention within the ecosystem of the nutrients released from the forest floor after burning. Thus, it is doubtful that understory burning of this intensity would result in any substantial increase in nutrient export in runoff or degradation of water quality. However, further research is needed to test this speculation.

The decrease in the cation exchange capacity immediately after the fire (Table 2) is probably due to selective burning of very fine particles high in exchange capacity. Note, however, that by November, 1977, the cation exchange capacity had increased to the point that it was not significantly lower than pre-burn levels. This may be due to the generation of organic exchange sites by accelerated decomposition during this period.

Exchangeable cation increases (Table 2) are attributed to ash, as discussed above. An important point is that the exchangeable

calcium, magnesium, and potassium greatly dominated exchange sites in both November, 1976, and June, 1977, 8 months after burning.

TABLE 1. Changes in the fine fraction (less than 2 mm) of the ponderosa pine forest floor following prescribed burning. Data are means and (standard errors).

	Organic Matter[1]	Calcium[2]	Magnesium[2]	Potassium[2]	Nitrogen[3]	Phosphorus[3]
	g/m^2	% of ash free oven dry weight				
Before burning (Oct. 1976)	1983(193)	1.44(.09)	0.64(.07)	.27(.03)	2.09(.13)	.244(.011)
After burning (Nov. 1976)	1585(117)	4.05(.92)	1.48(.03)	.48(.05)	2.40(.12)	.351(.024)
June 1977	1184(84)	4.92(.87)	1.33(.01)	.63(.10)	2.17(.16)	.396(.050)

1. N = 60 for each date, no compositing.
2. N = 40 for each date, no compositing.
3. N = 15 for each date, composited by fours.

TABLE 2. Changes in cation exchange properties of the less than 2 mm fraction of the ponderosa pine forest floor following prescribed burning, units are milliequivalents/100 g. Data are means (standard error).

	C.E.C.[1]	Calcium[2]	Magnesium[2]	Potassium[2]	Total Calcium, magnesium, potassium
	me/100g		me/100g		
Before burning (Oct. 1976)	52.3(2.7)	24.6(2.1)	9.2(0.1)	.93(.04)	34.7
After burning (Nov. 1976)	41.3(3.0)	30.1(3.3)	10.3(0.1)	1.27(.13)	41.7
June 1977	47.8(4.9)	34.3(2.8)	10.1(0.1)	1.31(.09)	45.7

1. N = 15, composited by fours

2. N = 9, composited by fours

TABLE 3. Areal changes in the nutrient content of the fine fraction of the ponderosa pine forest floor following prescribed burning, in g/m^2.

	Calcium	Magnesium	Potassium	Nitrogen	Phosphorus
Before burning Oct. 1976	28.6	12.7	5.34	41.4	4.84
After burning Nov. 1976	64.4	23.5	7.61	38.0	5.56
June 1977	58.3	15.8	7.46	25.7	4.69
Change from Oct. to Nov. 1976	+35.8	+10.8	+2.27	-3.40	+0.72
Change from Nov. 1976 to June 1977	-6.1	-7.7	-0.15	-12.3	-0.87

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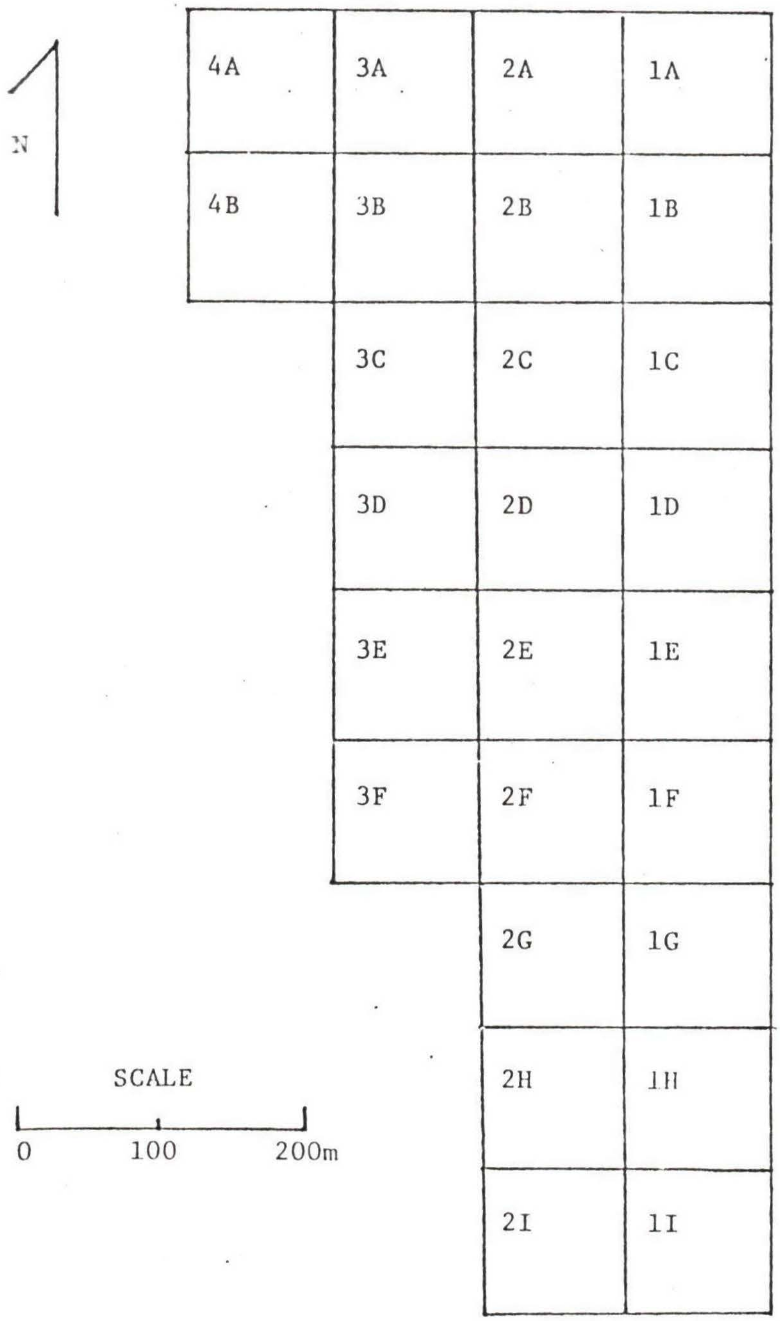
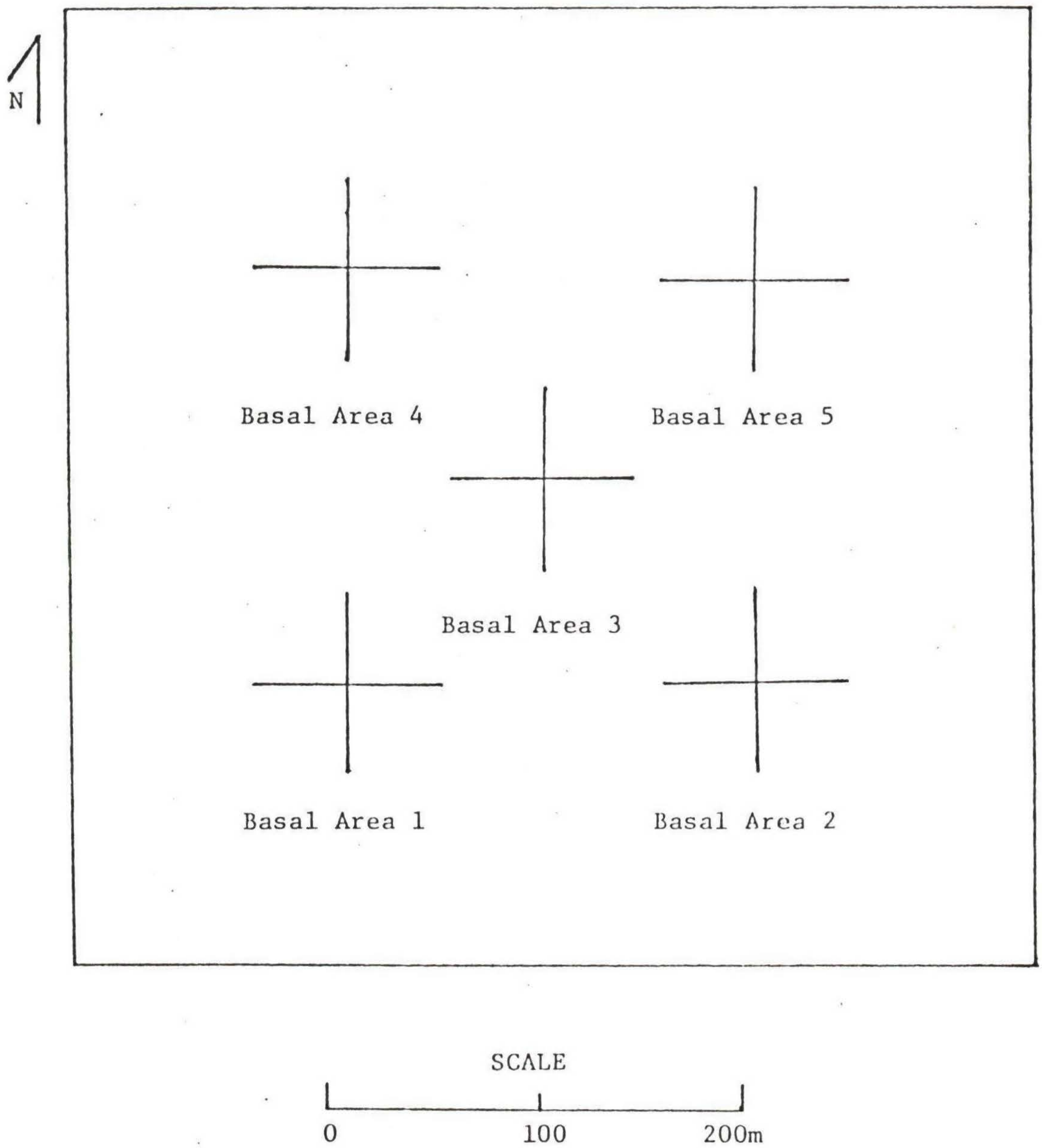


Map showing the Interval Burning Study area plot layout on Fort Valley Experimental Forest.



Map showing east-west and north-south lines that were used to divide basal area plots into quadrants and for sampling.